## I. Introduction

Recently the Coalition of C-Band Constituents (CCBC) commissioned the Alion Science and Technology to conduct a study of interference from ultra wideband transmitters to C-Band satellite systems[1]. Alion concluded that at the present authorized power levels eventually "the combined effects of UWB devices will overpower C-band reception and render it impossible "

We examined the Alion report and found several assumptions that are unrealistic and cannot be justified based upon published measurements or scientific literature. The Alion report has no references to any scientific literature. In addition, Alion gives no rationale for many of their assumptions. Their assumptions force their modeled environment to be dominated by line of sight UWB emitters, which leads to an overestimation of the received interference power at an earth station. These assumptions are unrealistic in any operational scenario.

For this study, we replicated the Alion emitter distribution and path loss models in Matlab. This enables us to examine and quantify correction factors to the Alion model.

In Section II, we consider the Alion baseline distribution of emitters and associated assumptions. For their baseline distribution, Alion suspends the emitters in free space with a random uniform distribution in height and a random uniform distribution in area in the region between 30m and 5 km. radius. We show that this, along with their chosen probabilities of path loss modes, leads to an interference model dominated by emitters with line of sight propagation modes.

Alion's baseline puts the emitters uniformly distributed in height between 0 and 100 meters, roughly the equivalent of random building heights to 25 stories or so. The only reasonable scenario where this would occur is in an urban environment with the emitters in buildings. Alion, however, included no building penetration loss in their model. In Section III, we consider the Alion model with building penetration loss included. We show that the inclusion of a *single* building penetration loss reduces their baseline interference power estimate by 7.3 dB, but further note that many UWB devices operating will likely be blocked by *several* buildings and/or trees and shrubs.

In Section IV we examine the Alion earth station antenna model. Alion used an FCC peak sidelobe mask to model the antenna. A peak sidelobe mask however overestimates the interference in scenarios where the emitters randomly surround the earth station. The Alion baseline has 1000 emitters uniformly distributed in azimuth between 0° and 360° around the earth station. A more accurate estimate is obtained by using an average sidelobe level. We model a commercially available antenna and repeat our Matlab analysis using an average sidelobe mask instead of the peak mask. This results in interference levels 7.4 dB lower than the Alion baseline

Section V addresses the activity factors of the UWB emitters. The activity factor accounts for devices that are not emitting continually (for example, digital cameras) and only emit when specific tasks are indicated (in the camera example, download images from the camera to a computer). Alion modeled UWB pulse transmitters with a pulse duty cycle of 20%, but assumed that all the emitters were on continually (100% activity factor) We show in Section V and in Appendix A that a reasonable activity factor is 4% based upon market research evaluating possible future use of UWB technology and target applications. We conservatively increase this to 10% to account for peak factors and uncertainties in future deployments. This results in another 10 dB correction factor to the Alion baseline numbers.

Section VI discusses Alion's choice for the earth station antenna elevation pointing angle. We point out that a $5^{\circ}$ elevation angle is overly aggressive for the most of the United States, and leads to exaggerated interference level estimates at the earth station.

In Section VII we examine Alion's path loss modeling. and show that Alion's modeling of propagation through foliage and buildings is inaccurate.

In Section VIII we provide corrections to Alion's conclusions based on the correction factors obtained in Sections III, IV, and V Using Alion's own analysis methodology and conclusions, we show that UWB emitter densities well beyond 60 devices per acre (more than a million in the modeled area) do not pose a threat to C-band earth stations.

Our concluding remarks are presented in Section IX.

## II. The Alion Spatial Emitter Distribution

In this section, we examine the Alion baseline distribution of emitters and the propagation modes Alion chooses for those emitters. We will make the following points

- The Alion model floats the emitters in freely in space. While the distribution of emitters suggests an urban scenario, the propagation mode probabilites are inconsistent with that scenario.
- The Alion model is predominantly a line of sight model. While obstructed propagation components are included, they are so far below the line of sight components as to be negligible. The line-of-sight dominance is due to the Alion's probabilistic modeling of the propagation modes, which Alion uses without any stated rationale or justification.
- There is no explicit modeling of building penetration loss.
- One cannot draw conclusions about the model at one emitter density and extrapolate them to higher densities without ignoring some basic phenomena, to be detailed in the following paragraphs.

Alion used 3 different emitter distributions in their report. Their baseline distributed the emitters uniformly in area. They also distributed emitters using both a normal or

Gaussian distribution about the base station and an inverse Gaussian distribution The Gaussian distribution concentrates the UWB emitters close to the earth station, while the inverse Gaussian distribution concentrates the emitters at the far ranges. Both of these distributions are specious. An earth station is not like a magnet, attracting or repelling UWB transmitters. Alion states that the inverse distribution could model an interference protection zone. That, however, would be an interference protection zone of several kilometers radius, which is impractical So, in the following, these two distributions are ignored because they are not representative of any realistic scenario. We focus our comments on the uniform distribution model. Most of the comments that apply to the uniform distribution apply to these other models also.

Alion's method of analysis was to choose a model for the distribution of emitters around an earth station, model the path loss from each emitter to the earth station, then add up the contributions from each emitter based upon an earth station antenna model.

They used a baseline emitter distribution composed of a uniform distribution over a annular area with radius between 30 meters and 5000 meters. Emitters within a radius of less than 30 meters were assumed to be within an interference protection zone and therefore prohibited. The emitters were also uniformly distributed in height between 0 and 100 meters.

The Alion baseline is a reasonable approach to modeling an urban scenario, with buildings uniformly distributed in height between 1 and 25 stories (100 meters ) or so in a circular region of radius 5 km. These building would have the UWB emitters located within them on random floors. This picture is one of a mixed urban model, with some propagation over the rooftops, some propagation of the "urban canyon" model [2], and some line-of-sight propagation.

The Alion study divided propagation into 3 modes of propagation, the free space or line-of-sight mode with incident power declining at a $1/r^2$ rate, a mode that Alion used to represent propagation through foliage with the power declining at a $1/r^3$ rate, and a mode that Alion uses to represent propagation through and around buildings with power declining at a $1/r^4$ rate, where r is the range to the earth station. In the following we discuss propagation in these modes, using the term LOS to mean line-of-sight and non-LOS to mean non-line-of-sight. The non-LOS modes are the "foliage" and "building" modes

Each emitter in the Alion study is assigned a mode of propagation probabilistically with the probabilities varying depending upon the emitters range to the earth station.

We programmed the Alion baseline (uniform area distribution of 1000 emitters) model in Matlab and ran a Monte-Carlo simulation composed of 1000 trial cases. Each trial was composed of random positioning of the emitters, and the random assignment of propagation modes (i.e. $1/r^2$, $1/r^3$, or $1/r^4$ propagation modes) and parameters according to the Alion report. The emitters here are all "on" 100% of the time and radiating with

EIRP of -41 3 dBm/MHz , the maximum allowable under current regulation. The results of the Monte-Carlo experiment are shown in Figure 1, below.

Figure 1 shows the received power spectral density (PSD) in units of dBm / MHz. as a function of the trial number. The blue, magenta, and green lines are the sum of the $1/r^2$ (i e. the free space LOS mode), the $1/r^3$ (foliage), and the $1/r^4$ (building) propagation modes, respectively, of each trial. Also plotted on the figure in red, but not visible, is the total received PSD. The red total PSD line is overlaid by the blue free space line. The non-line-of-sight (non-LOS) modes, which are the $1/r^3$ and $1/r^4$ modes, are well below the LOS mode, so that the blue LOS line essentially represents the total PSD line also. The non-LOS components in the Alion model don't contribute significantly to the total power seen by the receive antenna. The Alion model is essentially a distribution of LOS emitters with some non-LOS emitters thrown in that don't contribute significantly. This is due to the probabilities and assumptions in the Alion model.

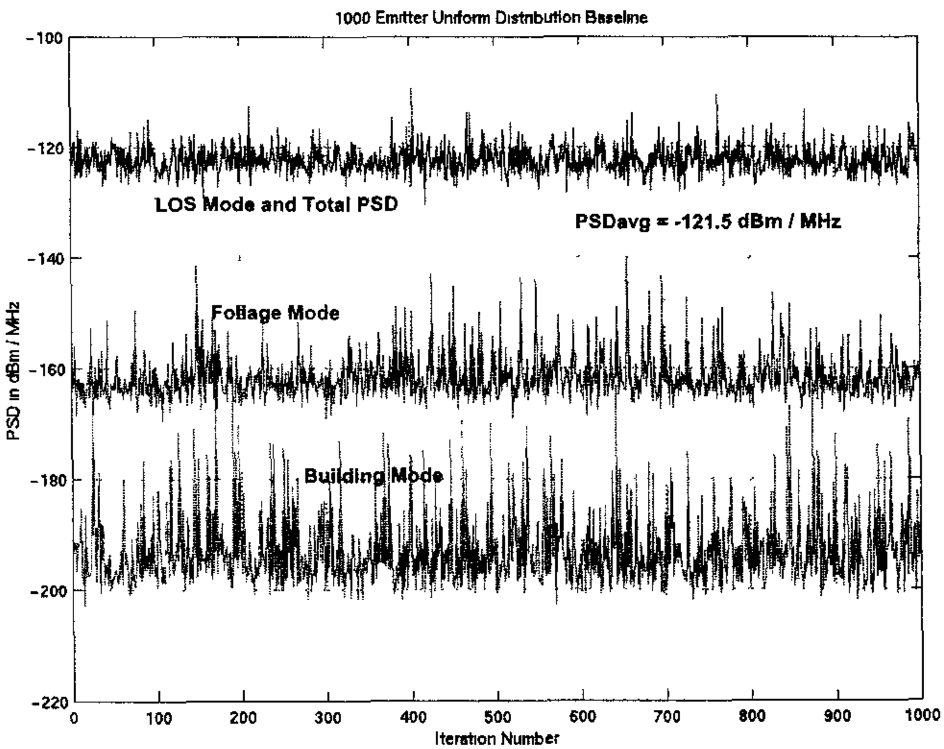


**Figure 1. 1000 Trials of the Alion Uniform Baseline.**

The probabilities that Alion used to assign the propagation modes are given in the original report in Table 3-1, which is reproduced here as Table 1. However, no justification for these numbers is provided, and they don't appear to represent any realistic environment.

| Range Bin (km) | Propagation Mode | | |
|---|---|---|---|
| | Percent $1/r^2$ | Percent $1/r^3$ | Percent $1/r^4$ |
| 0 03-1 | 90 | 5 | 5 |
| 1-2 | 70 | 15 | 15 |
| 2-3 | 50 | 25 | 25 |
| 3-4 | 30 | 35 | 35 |
| 4-5 | 10 | 45 | 45 |

**Table 1. Path loss assignments in the Alion model.**

Using these probabilities, the areas of each range bin, and 1000 emitters as a baseline, one can compute how many emitters are expected to be in each region. These values are shown in Table 2, below, rounded to the nearest integer.

| Range Bin (km) | Expected Number of Emitters per Propagation Mode | | |
|---|---|---|---|
| | Number $1/r^2$ | Number $1/r^3$ | Number $1/r^4$ |
| 0.03-1 | 36 | 2 | 2 |
| 1-2 | 84 | 18 | 18 |
| 2-3 | 100 | 50 | 50 |
| 3-4 | 84 | 98 | 98 |
| 4-5 | 36 | 162 | 162 |
| All | 340 | 330 | 330 |

**Table 2. Expected number of emitters in each bin for 1000 total emitters.**

In the ranges out to 3 km, there is a predominance of LOS emitters That is one reason for the dominant line of sight mode in Figure 1. It flows down from the probability assumptions above, but they don't seem to represent any physical environment.

The probabilities and number of LOS emitters don't make sense for the urban model. The emitter distribution seems to represent an urban area with building heights uniformly distributed between 0 and 100 meters, about 25 stories. In this environment, one might be able to look straight down a street for perhaps 200 meters or so, but not out to multiple kilometers in every direction. Yet the probability distribution puts 100 emitters spaced approximately evenly in azimuth in the range ring between 2 and 3 km with line-of-sight to the earth station antenna. On the average, that's one emitter every 3.6 degrees. LOS propagation out to beyond 3 km. isn't characteristic of urban areas, it more representative of rural flatlands

Consider for a moment Figure 2, below It represents a 4.5 meter earth station installed with it's center 3 meters in elevation. 100 meters away is a building that is 12 meters tall. That building will effectively shield the earth station from a line-of-sight to most of the emitters behind it. The distribution assumed by Alion suggests an urban distribution, but the probabilites show strong LOS modes out to beyond 3 km, which suggests flatlands.

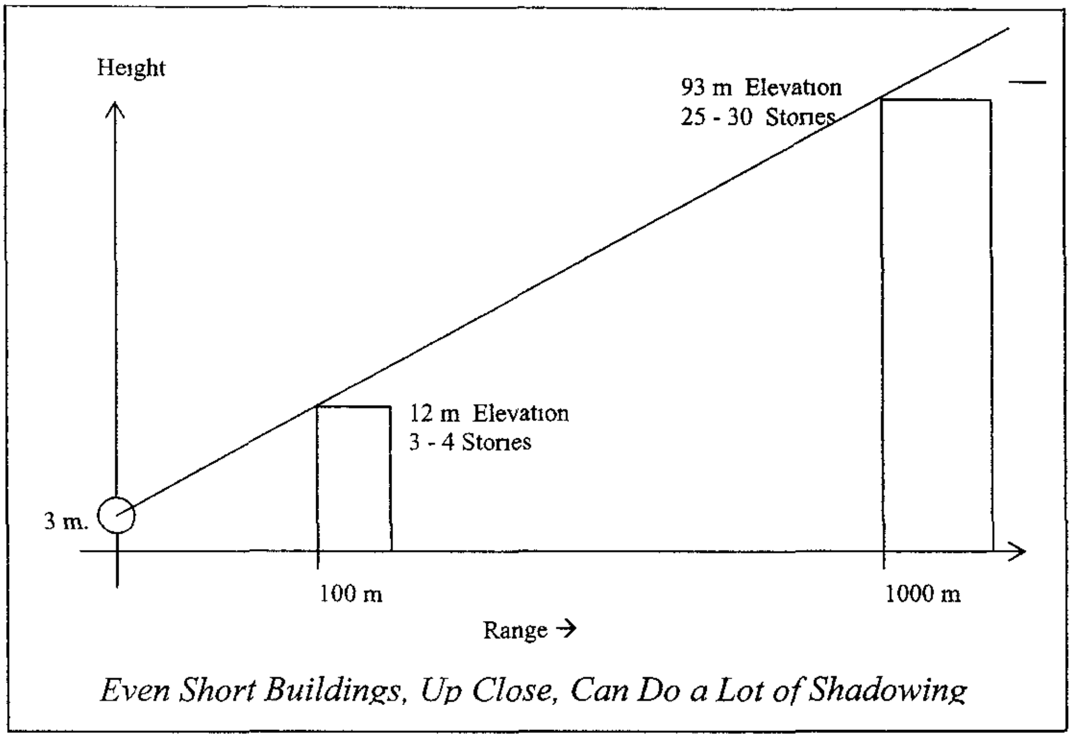


**Figure 2. A picture of a building shadow scenario.**

Another inconsistency is the variation in the propagation modes with height. There is none in the Alion model. In real situations, the higher the emitter, the higher the probability of having line-of-sight to the earth station, but if the emitter is located high above the ground, it will necessarily be inside a building and suffer building attenuation losses. Similarly, at low elevations, you will have very low probability of line-of-sight. In the Alion model, one can have an emitter at near ground level 4.5 km. from the earth station assigned a LOS mode of propagation. In real life, the probability of this occurring in an urban setting is virtually zero.

Another inconsistency is the lack of building penetration loss. The emitters are uniformly distributed in height between 0 and 100 meters. In reality, any emitter not at ground level would almost certainly be inside of a building. So, some building penetration loss should be included. We address building penetration loss in more detail subsequently.

Finally, in an urban scenario power should not scale linearly with the numbers of emitters. Doubling the density of emitters should not result in a 3 dB increase in the received power. The reason for this is that there is an implied relation between the emitters and the buildings that house them. Doubling the density implies that the building density should increase also, perhaps not doubling, but increasing. Since the building density increases, the probabilities for the various modes should change, with the probabilities for LOS modes decreasing -- more buildings imply less line-of-sight. So, doubling the density should result in something less than a 3 dB increase. This effect is not captured in the Alion model, where the emitters are hanging in free space with fixed probabilities.

An item that is missing from the Alion report is a reference to any studies or measurements that provide information concerning the probability of the various propagation modes. Alion provides no reference and we know of no such information.

## III. Building Penetration Loss

As almost any cellular operator will testify, building penetration loss is a significant factor in a wireless link budget Alion stated that their $1/r^4$ mode "represents losses through walls, obstacles, etc.", and did not explicitly model building penetration loss. The effect of this modeling is that the LOS emitters in their model have no building penetration loss. That is, Alion's model assumes emitters floating in space at heights to 100 meters with a direct line-of-sight to the earth station, with no building penetration loss. That is not reasonable. In a real scenario, all emitters above ground level would almost certainly be within buildings Furthermore, since the UWB devices that are expected to proliferate are indoor communication devices, most of the ground level devices will be indoor devices also.

There are several commonly used modeling tools available that model outdoor propagation. Some of the common ones are the Hata [3,9] model commonly used for cellular network planning and layout, the European COST [9] extension of the Hata model to PCS frequencies, and an ITU recommendation [2] for short range radio networks. All of these commonly used tools model outdoor propagation -- that is, from a point outdoors to another point outdoors. They provide estimated values for outdoor path loss. Building penetration loss is handled by adding an extra loss on top of the outdoor path loss. The extra value represents the loss in getting from the outdoor propagation environment to the indoor environment.

Since the subject of building penetration loss is of significant concern to cellular operators and other businesses, it has been studied extensively, although not at C-band. Some example values from the scientific literature are as follows. Durgin et al. [4]

reported a mean loss value of 14 dB at 5.8 GHz. Turkmani et al [5] reported building penetration losses of 12.8 dB at 2300 MHz. The ITU recommendation specifies a mean loss figure of 12 dB at 5.2 GHz for 40 mm outside wall thickness, but also has a table showing up to 50 dB losses for thicker stone and brick walls. The FCC in it's First Report and Order [15] references NTIA report 95-325 [16] and used 12 dB for building penetration loss for frequencies above 2900 MHz.

To investigate the impact of building penetration loss, we reasoned that most all of the emitters would in fact be in buildings. Using the Alion baseline distribution and probabilities, we assigned 10 dB of building penetration loss to 90% if the emitters selected randomly. We feel that 90% is very conservative because most of the forecast growth for UWB devices is for indoor applications, and the FCC has disallowed outdoor networks from supporting UWB based communications which will result in only periodic ad hoc types of communications. Similarly, we chose 10 dB for the average building penetration loss to be conservatively less than most published values. We then ran the 1000 trial simulation, with the result that the average PSD for the 1000 trials was -128.8 dBm / MHz, which is 7.3 dB less than the Alion baseline without building penetration losses

## IV. Antenna Modeling

Alion used the FCC peak sidelobe mask specified in 47CFR25.209. This mask is intended to limit radiation from earth station transmitters. However, for the present case where the antenna is receiving energy from essentially all azimuth angles, it is more accurate to use an average sidelobe level rather than a peak mask. The antenna sums the energy from all angles. Some of the energy will arrive in low sidelobe regions and some will enter from high sidelobe regions. An average sidelobe response accurately represents this scenario, whereas a peak mask or sidelobe level will overestimate the antenna's response.

To examine the difference between using the FCC mask and a real antenna, we analyzed a representative antenna for average sidelobe levels, compared it to the FCC peak mask and found an 8.43 dB difference. We then formulated a revised "average" mask. Using the average mask, we ran the our Alion simulation and found that the average mask reduces the received interference power average power spectral density from -121.5 dBm/ MHz to -128.9 dBm/MHz., a drop of 7.4 dB. The details are given below.

The FCC peak sidelobe mask is given by

$$\begin{array}{rl} 32-25\log_{10}(\theta)\ dBi & 1^\circ \le \theta \le 48^\circ \\ -10\ dBi & 48^\circ < \theta \le 180^\circ \end{array}$$

It is intended to limit power radiated power in off axis directions when the antenna is used with a transmitter Although the regulations allow some minor excursions above the mask, most manufacturers attempt to meet the FCC mask with margin. The manufacturers also have other incentives to keep the sidelobes low. In particular, sidelobes that fall on the warm earth degrade the G/T performance of the antenna, which impacts the noise performance of the satellite receiver system (antenna plus receiver). Because of this, sidelobe performance is a marketing item for antennas.

A typical example is the Andrew ES45P-1 antenna, a 4.5 meter earth station antenna (the same as the Alion study) with 44.2 dBi gain at 4.2 GHz (0.1 dB higher than the Alion study). Andrew publishes antenna patterns for this antenna on their website [6], with the regulatory peak sidelobe mask superimposed. There is a 4 GHz. receive pattern and a 6 GHz transmit pattern on the Andrew website. We used the 4 GHz. elevation receive pattern

Using the published data for this antenna, we manually read the pattern at 0.25 degree intervals over the angular range of the pattern, which was from -12 to +11.5 degrees, and put the data into Matlab for analysis. That data is shown below in Figure 3. We note several things from the data. First, the antenna sidelobes are somewhat asymmetrical. That is, the sidelobes on the left have a generally higher value than the sidelobes on the right. This is an elevation pattern, and probably was measured with one of the parabola's struts oriented vertically. Thus, we suspect that the left side of the pattern is looking through the strut, while the right side of the pattern is looking between the struts of the antenna. More importantly, observe that all sidelobes are well below the peak mask, which is shown in the red uppermost mask.

Using Matlab, we computed the average difference between the peak sidelobe mask and the measured antenna pattern. The average was over both the left and right sidelobe regions from -12 to +11.5 degrees, excluding the mainbeam region from -1 to +1 degrees. We found actual antenna was 8.43 dB lower on average than the peak sidelobe mask.

Therefore, we adjusted the peak mask by subtracting the 8.43 dB. The revised mask is shown in the figure as the lower mask (magenta). The revised mask is seen to lie slightly below the "eyeball average" of the left sidelobes, and slightly above the right sidelobes, as expected. We feel that this is still conservative, in that the revised mask probably includes a pattern cut through a strut, whereas the sidelobes at most other angles would more reasonably be expected to look like the right, non-strut pattern. In spite of this, we did not make further compensation in the close in sidelobe part of the mask. We note in passing that the FCC's 25 $\log_{10}(\theta)$ sidelobe roll-off with angle is a pretty good fit to this antenna's actual sidelobe roll-off.

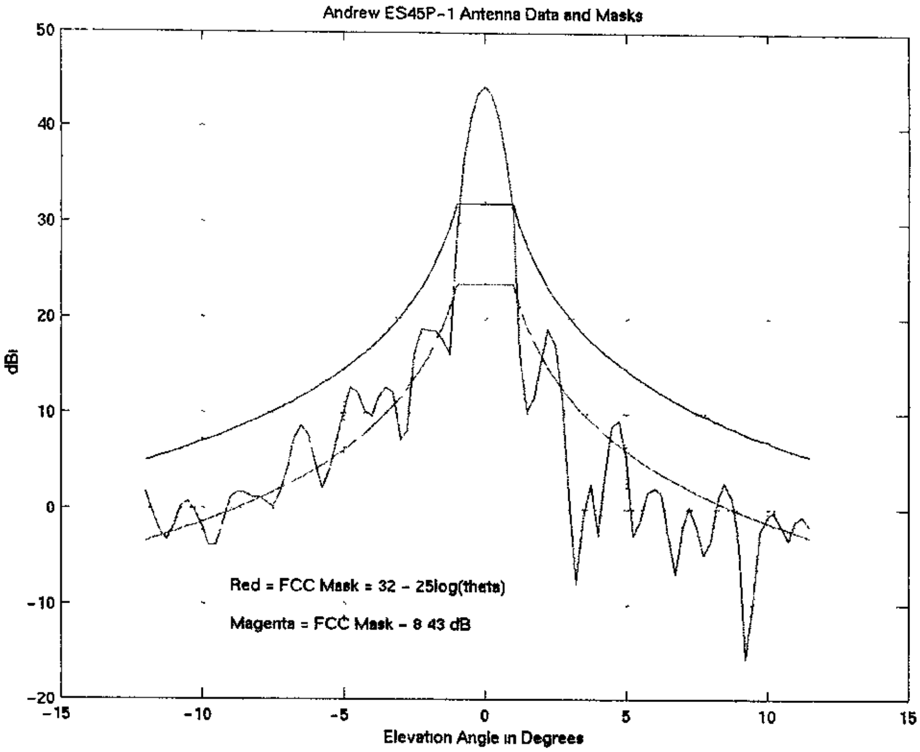


**Figure 3. Andrew ES45P-1 antenna pattern and masks.**

We also made a reasonable adjustment to the peak mask in the far sidelobe region, which is specified as peaks less than -10 dBi for angles greater than 48 degrees. Again, peak sidelobes are the wrong criteria for measuring the true received power from the antenna when energy is incident from all directions -- the average sidelobe level is correct. To adjust for this, we somewhat arbitrarily subtract 3 dB from the far sidelobe peak mask, resulting in -13 dBi

Since we changed the levels of the close in sidelobe mask and the far sidelobe mask differently, the breakpoint between the two changes to 29 degrees as a result. The revised average sidelobe mask is thus:

Average Sidelobe Mask:

$$\begin{array}{rl} 23.6 - 25\log10(\theta)\ dBi & 1^\circ \le \theta \le 29^\circ \\ -13\ dBi & 29^\circ < \theta \le 180^\circ \end{array}$$

We put this mask into our Alion baseline program and reran it. The bottom line results is that the received power spectral density drops by 7.4 dB when using the average mask instead of the peak mask, from -121 5 dBm / MHz to -128.9 dBm / MHz.

## V. The Activity Factor of the UWB Emitters.

The Alion analysis did not account for the fact that not all UWB devices in a particular area will be transmitting at the same time. Note that the 20% duty cycle discussed in Section 3 3 2.4 in the Alion report only refers to the ratio of the pulse duration to the pulse repetition period, and not the application level activity factor referred to in this section. In particular, Section 3.3.2.4 of the Alion report talks about impulses with a pulse repetition frequency (PRF) of 400 MHz and a 20% duty cycle. However, assuming these are FCC compliant devices meeting the -41 3 dBm/MHz average power spectral density limits, there will be no difference in average received power within the bandwidth of the C-band receiver between pulses with a 20% duty cycle and a 100% duty cycle, since the bandwidth of the receivers is much less than the PRF. Therefore, this duty cycle does not account for the overall activity factor resulting from the applications.

When doing an aggregate interference study involving a large population of devices, the usage model and realistic activity factors result in only a small number of devices communicating simultaneously. Averaging this low activity factor over a large population significantly reduces the total aggregation of potential interference at any particular time, and this factor should be included in any aggregate interference analysis. In particular, Intel has studied a number of usage scenarios and estimated the activity for different applications based upon internal market research, and the results were presented to the WGPT SE24 group in Europe to better estimate the aggregate interference of multiple devices into Fixed Wireless Access (FWA) systems [17]. An independent study of usage models and activity factors was also presented to the WGPT SE24 group recently by Sony [18]. Intel and others are actively trying to drive consensus on the method of analyzing the aggregate interference within the WGPT SE24 group which includes activity factors as well as expected piconet organization [19].

The details of the usage models and activity factors are found in Appendix A, but a brief summary is included here. The study included both the office and home environments and many different applications which may utilize UWB technology in the future. In particular, in the office environment, users were categorized into two different classes: a 'power user' is someone who typically takes advantage of all the latest technology trends and would have several UWB enable devices, and an 'average user' who may have a few UWB enabled devices but only uses the most popular applications. In addition, the office environment may have a 'high-tech conference room' which also includes UWB enabled devices, and this usage model is also included in the overall UWB device activity. A summary of the results are presented in the table below, and the details are left to the appendix.

**Table 1. Summary of overall office building activity factor**

| User | Overall user activity | Population density (% of employees) | Overall building activity |
|---|---|---|---|
| Power user | 8 38 | 15 | 1 26 |
| Average user | 2 70 | 80 | 2 16 |
| Average conference room | 11 42 | 5 | 0 57 |
| **Total average office building activity (average 'on-air' %)** | | | **3.99** |

The above table shows that the estimated overall activity factor for UWB devices is less than 5%. This means that, on average, less than 5% of the UWB enabled devices present in an office environment will be expected to be operating at the same time. As a comparison, it is reported in ITU-R M 1454 that the activity factor for RLANs is currently significantly less than 1% based upon measurements, with a 'high proposed value' of 5% in the future. So, these results seem to be in agreement with other types of wireless applications.

A similar analysis was done for the home environment, where homes were categorized into three different groups, based upon different levels of technology adoption. The results are summarized in the table below.

**Table 2. Summary of overall home activity factor**

| Average Home Activity | Overall cluster activity | Population density (% of homes) | Overall average activity |
|---|---|---|---|
| Power Home 1 | 13 23 | 5 | 0 66 |
| Power Home 2 | 7.63 | 25 | 1.90 |
| Power Home 3 | 1 12 | 55 | 0.62 |
| Non-UWB Home (or << 1% UWB usage) | 0 | 20 | 0 |
| **Total average home activity (average 'on-air' %)** | | | **3.18 %** |

Again, the estimated overall average activity factor appears to be less than 5%. Since these studies are only projections of possible usage scenarios, a very conservative activity factor of 10% could be applied to the aggregate analysis to provide more realistic results to the possible interference from a number of devices in a particular area.

## VI. Earth Station Main Beam Elevation Angle

Alion uses an earth station main beam elevation angle of 5 ° for their study. We questioned the appropriateness of that angle, in that it seemed too low. We obtained the following elevation angles necessary to receive the Galaxy series of satellites from Boston, Ma and Seattle, Wa These data were obtained from the PanAmSat Corporation, www.panamsat.com .

| C-Band Satellite | Sat. Latitude (deg W) | Boston elevation | Seattle elevation |
|---|---|---|---|
| Galaxy 10R | 123 00 | 18 89 | 35.34 |
| Galaxy 11 | 91.00 | 37 10 | 27.49 |
| Galaxy 12 | 74.00 | 41 04 | 18.41 |
| Galaxy 1R | 133.00 | 11.84 | 34.36 |
| Galaxy 3C | 95.00 | 35.43 | 29.25 |
| Galaxy 3R | 111 10 | 26.71 | 34.25 |
| Galaxy 4R | 99.00 | 33 54 | 30.82 |
| Galaxy 5 | 125.05 | 17 47 | 35.28 |
| Galaxy 9 | 127 00 | 16.10 | 35.15 |

**Table 3. Earth station beam elevation angles for the Galaxy series of satellites when viewed from Boston and Seattle (from panamsat.com)**

These satellites are shown in Figure 4. The two smallest elevation values are 11.8 ° and 16 1° These values, when used in our Alion baseline simulation, result in improvements (reduction) in the interference power at the earth station of 1.9 dB and 2.8 dB, respectively

While we realize that there will be some users who view extremely low elevation satellites, this will not be a standard operation. Also, those earth stations will not be at the center of urban areas with surrounding building heights to 100 meters. At a 5 ° elevation angle, the center of the earth station receive beam is only 100 meters high at a range of 1143 meters from the antenna. So, the low elevation angle is inconsistent with a uniform distribution of emitters between 0 and 100 meters high.

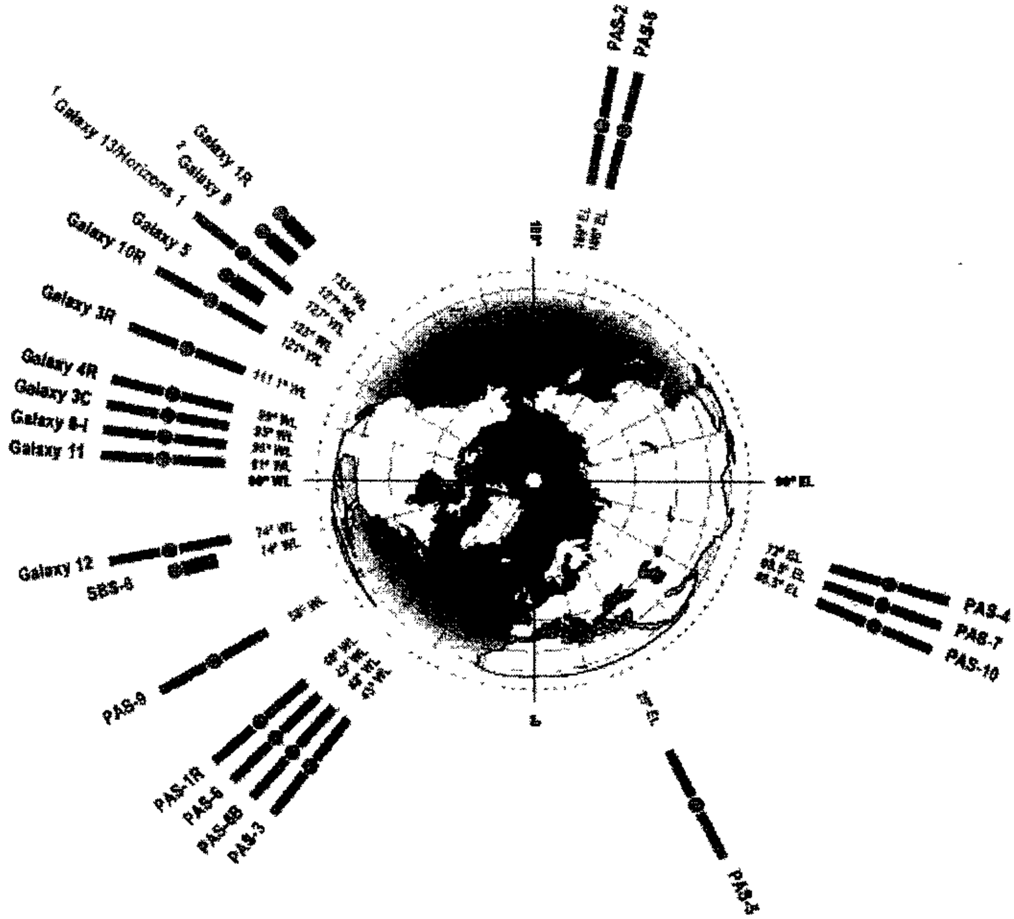


Figure 4. PanAmSat's family of satellites.

## VII. Path Loss Modeling.

The Alion baseline assigns propagation modes representing free space, foliage, or buildings to the emitters based upon probabilities. In Section II it is shown that the emitters with free space modes dominate the interference power at the earth station In the arguments below, we show that the path losses for the foliage and building propagation modes are too small That is, the power received in these modes is overestimated

Alion models the path loss in dB through space as $Lp = Lr + Lf - 27.56$ , where Lp, Lr, and Lf are the total path loss, the path loss due to range, and the path loss due to frequency, respectively, and all parameters are in dB The equation can be derived from the Friis formula for the free space coupling between two antennas, in this case isotropic antennas.

**Path Loss Exponents**

The path loss due to range, Lr, is modeled as $Lr = 10 \log_{10}(r^{\alpha}) = 10\, \alpha \log_{10}(r)$ . The exponent $\alpha$ is the path loss exponent. Alion chooses $\alpha$ to be 2, 3, or 4 to represent free space propagation, propagation through foliage, or propagation through buildings, respectively They assume that the propagation through the modeled environment as a probabilistic weighted sum of the various propagation modes. This is not the standard approach to propagation modeling. Normally, one models an environment such as a dense urban, suburban, or rural environment and chooses a propagation model including a single path loss exponent to represent this environment. The use of 3 path loss exponents in a random mix is novel, but does not have any measurements supporting the model. Therefore, it begs two questions: (1). Are the exponents correct for what they attempt to represent? and (2) Is the probabilistic weighting of the exponents per emitter an accurate representation of a realistic propagation environment? We believe the model should be modified to include more widely published models and realistic path losses supported by actual measurements.

Alion used a path loss exponent value of 3 to represent propagation through foliage. We compare this value to those of the recently developed IEEE 802.16 channel model [7]. We choose the 802.16 model because it models tree terrain and is appropriate at the frequencies of interest here. It models propagation through suburban or light urban areas with three terrain types -- hilly terrain with many trees, flat terrain with few trees, and terrain with intermediate hills and trees. The 802.16 propagation model development was chaired by Vinko Erceg, a researcher in wireless propagation [8, 10, 11, 14], and is based on data collected in an extensive channel measurement program conducted by AT&T Wireless.

IEEE 802.16 is a fixed wireless standards group, and their channel model is intended to model fixed wireless scenarios These scenarios have a base station with antennas on a base station tower and subscribers in homes or businesses with antennas at 2 meter heights with correction factors for higher subscriber antennas. So, the basic model has the energy shooting over and through the trees from a high base station to a lower subscriber Therefore, the path loss exponent is a function of emitter height in the 802.16 model This is similar to Alion's scenario of emitters with heights randomly to 100 meters transmitting to an earth station at ground level.

Figure 5 shows the path loss exponents used in the 802.16 channel model for the 3 types of terrain and the three Alion path loss exponents for buildings, foliage, and free space. In general, for the three 802 16 models, the path loss exponents are between 3.5 and 4.2

for high base stations, increasing to 5 5 to 6 for low base stations. This is expected, because with high base stations the energy is traveling mostly over the trees, but with low base stations the energy propagates mainly through the trees, with more loss.

In comparison, the Alion model for foliage (magenta) is constant at 3 for all heights. Compared to the 802.16 model, the Alion model has much less loss. So, when compared to the 802 16 model, the Alion model overestimates the energy received at the earth station for emitters with propagation modes through foliage.

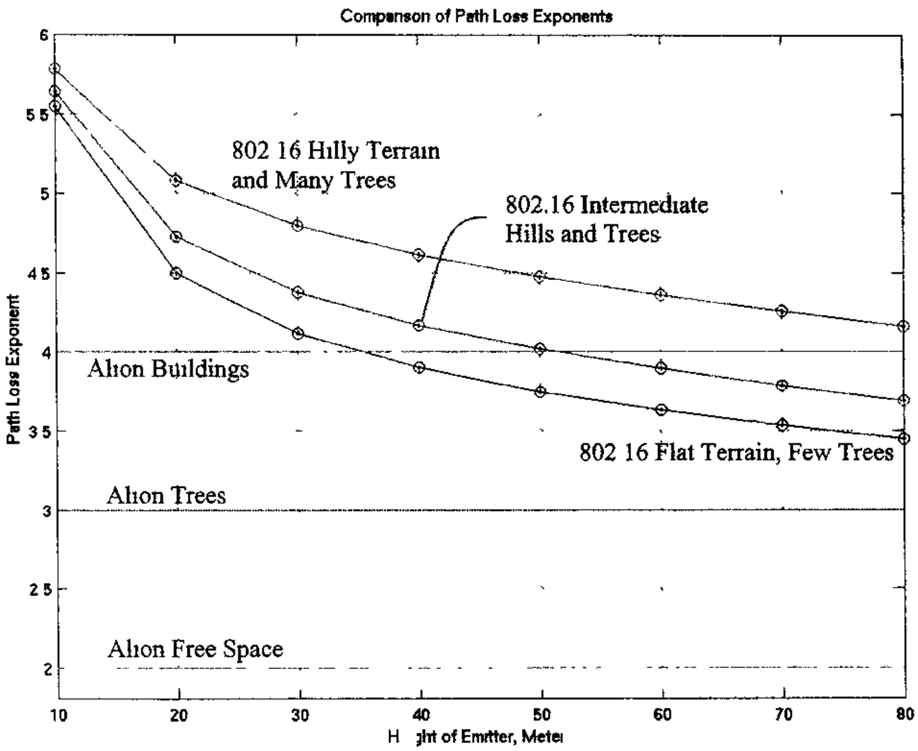


**Figure 5.** A comparison of path loss exponents between the 802.16 Suburban Models and the Alion model.

Alion's choice of 4 for the path loss exponent representing building propagation is roughly comparable to the values used in several other models, notably the Hata model [3] and also the recommendation from the ITU for modeling short range outdoor local area networks [2]. These models, however, are used for modeling propagation over rooftops, with diffraction serving to bring the energy down to street levels. For some emitters in the baseline scenario, rooftop models may be appropriate. However, for emitters in the lower levels of buildings, the "urban canyon" [2, section 4.2.2] model is more appropriate This is not adequately modeled by simple $1/r^4$ propagation with it's exponent of 4.

Propagation through an urban canyon is characterized by diffraction and reflection from buildings and is not modeled properly by simple path loss exponents. The ITU recommends computing separate reflection and diffraction losses at corners depending upon street widths and the position of the emitter and receiver on the streets to compute path losses for these scenarios. That requires an accurate model of the city streets and buildings, which is beyond the scope here.

To get a feel for the ITU urban canyon propagation, we used the ITU recommendation procedure to compute the path loss for 2 scenarios and then computed an "equivalent" path loss exponent. Both scenarios had street widths of 20 meters and a single intersection with 90 degree corners. For the first scenario, we placed the emitter and test receiver 50 meters from the corner on different streets, resulting in 100 meter total range (around the corner). For the second scenario, we moved the emitter and test receiver to locations 100 meters from the corner, a doubling of the range. The path losses for the two computations were 89.4 and 110.1 dB, with a difference of 20.7 dB. Simple $r^4$ law propagation would predict a 12 dB difference. Although it is incorrect to analyze the problem with simple path loss exponents, the 20.7 dB result for a doubling of the range is equivalent to a path loss exponent of 6.9 The path losses from propagation around multiple corners rapidly become huge.

In addition, there is the possibility of ducting along the street corridors in urban canyons. This can lead to near line-of-sight attenuation factors down streets (but not around corners). Our conclusion is that the urban canyon scenario, with the emitters below the rooftop levels of the buildings, is not easily modeled by a simplistic path loss model employing path loss exponents. For accurate predictions a more complex model, such as a ray-trace model, is required.

**The frequency loss factor, Lf**

Alion models the loss with frequency as 20 $\log_{10}(f)$, or 10 $\log_{10}(f^2)$, with f measured in MHz. This is true for free space propagation, but not true for urban or suburban multipath environments. Instead, there is a substantial scientific literature showing that a larger value for the frequency loss factor is more accurate. Here are a few examples. The Hata propagation model for 900 MHz. propagation is based on the extensive propagation measurements of Tokyo, Japan, conducted by Okumura et al. [12] It uses the frequency loss exponent value of 2.6. The European Cooperative for Scientific and Technical Research (COST) [9] working group 231 published an extension to the Hata model for use at PCS frequencies that uses an exponent of 3.39. Greenstein and Chu investigated the issue of proper frequency loss exponent in [13] and concluded that the use of an exponent value of 2.6 is generally valid from 500 MHz. to 11 GHz.

The frequency loss factor from the Alion model ( 20 $\log_{10}(f)$ ) is 72 dB, whereas the loss factor in using 26 $\log_{10}(f)$ as recommended by Greenstein is 93.6 dB, both computed at a frequency of 4000 MHz That is a 21.6 dB overstatement of power from the Alion model. This would apply to the non-LOS emitters in the Alion scheme. That is, it would apply to those emitters assigned an $r^3$ or $r^4$ path loss.

## VIII. Corrections to Alion's Conclusions

In this section we examine Alion's conclusions, add three correction factors discussed previously in this report, and show that there is no potential interference problem to C-band earth stations

Alion, in their conclusions, present recommended reductions in UWB power as a function of emitter density and earth station elevation angle in their Figure 6-7. Their analysis, as we have shown in Sections II, III, and IV, does not include building penetration loss (at least a -7.3 dB correction), an earth station antenna modeled upon average sidelobe levels (at least a -7.4 dB correction), or device activity factors (at least a -10 dB correction). These factors add up to at least -24 7 dB of reduction in the aggregate UWB power seen by the earth station antenna.

Alion's Figure 6-7, in their worst case 5° elevation scenario, shows that 60 UWB devices per acre can coexist with the earth station if there is a 19 dB reduction in aggregate interference power. 60 UWB devices/acre is equivalent to 15 devices / household, assuming 1/4 acre home lots. For higher antenna elevation angles, 60 devices per acre are allowed with even less power reduction. Here we have presented correction factors to the Alion analysis that achieve at least 24.7 dB of reduction in interference power, which allows device densities greater than Alion's Figure 6-7 considered. This clearly shows that there is no interference problem to C-band earth stations from UWB deployments, even in extremely dense environments.

These correction factors are conservative. The building penetration loss correction factor of -7 3 dB is obtained by randomly assessing 90% of the UWB emitters a building penetration loss. In reality, almost all of the emitters will be indoors and thus should incur the loss. Also, we assign a loss factor of -10 dB to those 90%, where most sources recommend a higher loss figure (the FCC mentions 12 dB in their R&O [15]). So, where we have a correction factor of -7.3 dB, it could easily approach -12 dB in reality.

Similarly, the device activity factor was estimated to be 4% (-14 dB correction), but we increased this value to 10% to be conservative, which results in the -10 dB correction factor that we use

Finally, we apply these correction factors to the Alion model, which is dominated by UWB emitters with line-of-sight propagation modes. A more realistic modeling of the environment would reduce the earth station interference power independent of these correction factors.

## IX. Conclusions

A critical look at the Alion study shows that it is based on many unrealistic assumptions that lead to conclusions that do not reflect real-world operational scenarios. The Alion study and report has the following problems:

- The Alion baseline distributes the UWB emitters with a random distribution suitable for modeling an urban scenario, but "floats" the emitters in space with no real-world obstructions, including buildings.
- The propagation mode probabilites are inconsistent with an urban scenario modeling, although the emitter distribution is inconsistent with any other scenario.
- The propagation mode probabilities are chosen ad-hoc, with no stated rationale.
- The propagation mode probabilities that Alion chose for their baseline scenario insure that the line-of-sight emitters dominate the power received at the earth station. That is inconsistent with an urban scenario.
- There is no adjustment of mode probabilites based upon height. Alion permits emitters 100 m high to be assigned a "foliage" propagation mode, and emitters at low height and long range to be assigned a line-of-sight propagation mode.
- Once the baseline result is obtained, Alion uses simple linear scaling of interference power with emitter density to compute power levels. In actuality, increased emitter density should be coupled to increased building density, so that increased emitter density should be accompanied by a reduction in the line-of-sight probabilities. This reduction does not occur in Alion's approach.
- Alion includes no building penetration loss in their link budgets, yet the major deployment of consumer UWB devices will be indoors (by regulation).
- Alion models the earth station antenna using a specification for peak sidelobe levels. For summing interference power incident from all directions, an average sidelobe level is appropriate.
- Alion chose to model the earth station antenna when pointed with an elevation angle of $5^{\circ}$ This exaggerates the interference power levels. From the continental US, almost all satellites are above $15^{\circ}$ with only a few lower
- The $5^{\circ}$ pointing angle puts the earth station receive beam 100 meters high at a distance of 1.14 km. from the earth station, inconsistent with an urban model.
- Alion includes no activity factor in their analysis, and has all of their UWB emitters on continually. Our analysis shows that the expected activity factors will be approximately 4%. That is, only 4% of the UWB emitters will be "on" an any one time.
- The chosen value of 3 for the path loss exponent to represent propagation through foliage is too low, and inconsistent with the 802 16 model, which is based upon measured propagation.
- The chosen value of 4 for the path loss exponent to represent propagation through building environments is too low to represent the complex "urban" canyon environment.

In Section VI of this report, we showed that the addition of just 3 of these factors to the Alion analysis results in a reduction of the estimated interference power at the earth station by at least 24.7 dB The correction factors account for building penetration loss, more accurate earth station antenna modeling, and UWB device activity factors. Alion's own conclusions show that a reduction of 19 dB permits the coexistence of UWB devices at a density of 60 devices per acre with the modeled earth station (Alion's Figure 6-7). 60 devices per acre equates to well over 1 million devices in the modeled 5 km. radius. This shows that the interference from UWB transmitters is not harmful, given the large number of devices necessary to provide an effect on C-band receivers. Furthermore, it should be noted that the analysis still relies upon Alion's questionable assumptions, such as linear scaling of power with emitter densities and a heavy contribution of line-of-sight emitters. These assumptions still make the analysis pessimistic. In reality, significantly more than 1 million UWB transmitters can be deployed in the modeled area without causing harmful interference to C-band receivers.

## X. References


1 Evaluation of UWB and Lower Adjacent Band Interference to C-Band Earth Station Receivers, Final Report, Alion Science and Technology, Feb. 11, 2004, Prepared for the Coalition of C-Band Constituents, available at http.//gullfoss2.fcc gov/prod/ecfs/retrieve cgi?native_or_pdf=pdf&id_document=6515782801

2 Recommendation ITU-R P1411-2, Propagation data and prediction methods for the planning of short - range outdoor radiocommunications systems and local area networks in the frequency range 300 MHz to 100 GHz., The International Telecommunications Union Radiocommunication Assembly

3 M Hata, "Empirical formula for propagation loss in land mobile radio services, *IEEE Trans Vhe. Technol*, vol 29, pp 317-325, Aug , 1980

4. G Durgin, T S Rappaport, and H Xu, "Measurements and Models for Radio Path Loss and Penetration Loss In and Around Homes and Trees at 5 85 GHz," *IEEE Trans. Comm.*, vol 46, no 11, Nov. 1998, pp 1484 - 1496

5 A. M D Turkmani and A F Toledo, "Propagation into and within Buildings at 900, 188, and 2300 MHz," *IEEE Veh Tech Conf*, 1992

6 Andrew Corporation ES45P-1 Antenna Specification Internet Page, http //www andrew com/products/antennas/esa/6237.aspx

7 Vinko Erceg et al , Channel Models for Fixed Wireless Applications, IEEE 802.16 Broadband Wireless Access Working Group, available at http://ieee802.org/16/tg3/contrib/802163c-01_29r4.pdf

8 V. Erceg et al , "An empirically based path loss model for wireless channels in suburban environments," IEEE JSAC, vol 17, no 7 , July 1999, pp 1205-1211

9 Theodore S Rappaport, Wireless Communications· Principles and Practice, Second Edition, Printice-Hall, Upper Saddle River, New Jersey, 2002

10 Vinko Erceg et al., " A model for the multipath delay profile of fixed wireless channels,", *IEEE JSAC*, vol 17, no 3, March 1999, pp 399-410

11 L J Greenstein, V Erceg, Y S Yeh, and M. V Clark, " A new path-gain/delay-spread propagation model for digital cellular channels,", *IEEE Trans Veh Technol.*, vol. 46, no 2, May 1997

12 T Okumura, E Ohmori, and K. Fukuda. "Field Strenght and Its Variability in VHF and UHF Land Mobile Service," Review Electrical Communication Laboratory, vol 16, no. 9-10, pp 825 - 873, Sept - Oct 1968

13 T S Chu and L J Greenstein, " A quantification of link budget differences between the cellular and PCS bands," *IEEE Trans Vhe Technol*, vol 48, no 1, January 19999, pp. 60-65

14 L J Greenstein and V Erceg, " Gain reductions due to scatter on wireless paths with directional antennas," *IEEE Communications Letters*, vol. 3, no 6, June 1999

15 FCC First Report and Order, ET Docket 98-153, Adopted Feb. 14, 2002, Table 7, pg. 52

16. Lynette H Loew, Yeh Lo, Michael Laflin, and Elizabeth E Pol, Building penetration measurements from low-height base stations at 912, 1920, and 5990 MHz, , NTIA Report 95-325, Sep 1995, pg 43

17 Jeff Foerster, Adrian Stephens, "Response to the "Revision of UWB and FS coexistence report (Annex 5-1)" concerning aggregate UWB interference into FS systems," contribution to WGPT SE24, Meeting 18, December 2002

18. Chris Walden, "Ultra Wideband and Europe," contribution to WGPT SE24, Meeting 24, February, 2004.

19 Fabrice Labourasse, Mikhail Lyakh, "UWB characteristics and proposal for alternative scenarios and statistical approach", contribution to WGPT SE24, Meeting 24, February, 2004

## Appendix A. UWB applications and activity factors

There are many anticipated uses for UWB technology that take advantage of one or more of the following unique properties of UWB radios: low power consumption, low cost due to high integration (especially CMOS integration), very high data rates, and accurate position location. As with many engineering trade-offs, not all of these device characteristics will be possible at the same time. Therefore, different devices will be designed to take advantage of these different characteristics, depending on the application.

This appendix describes various environments where UWB devices are expected to operate, and the characteristics of operation in terms of the expected activity and 'on-air' time. This information is useful and necessary when trying to estimate the effect of the aggregation of a large number of devices, since these devices will not be transmitting most of the time. For example, it is reported in ITU-R M.1454 that the activity factor for RLANs is currently significantly less than 1%, with a 'high proposed value' of 5% in the future. Since UWB devices are expected to be operating in similar environments and applications, similar activity factors might be expected. An investigation of the 'typical' usage scenarios will help to more accurately quantify this activity factor for UWB based devices. The applications and usage models described below are based upon a number of presentations made to the IEEE 802.15.SG3a study group investigating a high-rate, short range physical layer extension that is anticipated to use UWB technology. Additional data has been gathered through internal market research, when available, and through reasonable future projections.

Two main environments are considered for the widespread deployment of UWB devices, an office and a home. Industrial applications are not addressed in this contribution, and it is assumed that outdoor applications will be very low density and limited to handheld peer-to-peer type of connectivity, since the FCC has disallowed UWB technology to be used for outdoor fixed services.

For the office and home environments, the target data rates can be viewed as falling into three categories: low (10 Mbps), medium (100 Mbps), and high rates (250 Mbps). The low-rate devices are power and cost sensitive and would be designed to operate only at lower data rates.

The following sections describe in more detail the anticipated applications that are expected to take advantage of UWB technology. Note that the usage models and activity percentages given below are only 'best guess' estimates based upon market data available to us and past experiences with similar technologies (wired USB, for example). Conservative estimates were made as far as possible to ensure that the final activity factor represents a worst case for interference evaluation.

## I. Office environment

One compelling application for UWB technology is to provide a very-high rate, short-range wireless connection to replace the current wired USB connection. This will enable greater mobility for the user and potentially create new applications from which consumers could benefit. In order to simplify the vast range of possible applications that could be enabled by UWB, the following tables highlight possible usage models for the office environment based upon a 'Power User' and an 'Average User' Since not all workers in an office share the same desktop configurations and usage, this distinction enables the overall activity factor to account for a mix of users that typically use all the latest technology from more average users that may have a mix of new and old (wired and wireless).

**Table 1. Device and usage scenarios for a 'Power User'**

| Devices and usages scenarios | Data rate requirements (Mbps) | % of link rate (when active) | Daily usage | Daily usage based on 8-hour day (%) | Overall activity (%) |
|---|---|---|---|---|---|
| Mice/ tracking balls/ pointers (low rate) | 0 016 | 0 16 | 45 min/hour | 75 | 0.12 |
| Keyboards (low rate) | 0 016 | 0.16 | 45 min/hour | 75 | 0.12 |
| Headset (low rate) | 0 448 | 4 48 | 3 hours/day | 37.5 | 1 68 |
| Laser printer (low-end) (medium rate) | 100 | 100 | ~ 2 Gbyte of files per day ~ 2 min/day 'on air' | 0.42 | 0.42 |
| PDAs for file downloads (calendar/email synchronization) (medium rate) | 100 | 100 | 2x daily @ 100 Mbyte each ~ 1 min total (max) | 0.21 | 0 21 |
| Wireless monitor (laptop to external monitor w/compression) (high rate) | 10 | 4 | 8 hours/day | 100 | 4 |
| Scanner (high-end) (high rate) | 250 | 100 | ~ 2 Gbyte of files per day ~ 2 min/day 'on air' | 0 42 | 0 42 |
| External Hard-drive for drive backups (high rate) | 250 | 100 | 2x daily @ 2 Gbyte each ~ 2 min each (max) | 0 42 | 0.42 |
| Internet connection (high rate) | 250 | 100 | | 1 | 1 |
| **Total activity for Power user** | | | | | **8.4 %** |

### Table 2. Device and usage scenarios for an 'Average User'

| Devices and usages scenarios | Data rate requirements (Mbps) | % of link rate (when active) | Daily usage | Daily usage based on 8-hour day (%) | Overall activity (%) |
|---|---|---|---|---|---|
| Mice/ tracking balls/ pointers (low rate) | 0 016 | 0.16 | 45 min/hour | 75 | 0 12 |
| Keyboards (low rate) | 0 016 | 0 16 | 45 min/hour | 75 | 0 12 |
| Laser printer (low-end) (medium rate) | 100 | 100 | ~ 1 Gbyte of files per day ~ 2 min/day 'on air' | 0 42 | 0 42 |
| PDAs for file downloads (calendar/email synchronization) (medium rate) | 100 | 100 | 2x daily @ 100 Mbyte each ~ 1 min total (max) | 0 21 | 0.21 |
| External Hard-drive for drive backups (high rate) | 250 | 100 | 2x daily @ 1 Gbyte each ~ 2 min each (max) | 0 83 | 0 83 |
| Internet connection (high rate) | 250 | 100 | | 1 | 1 |
| **Total activity for Average user** | | | | | **2.7 %** |

### Table 3. Device and usage scenarios for a 'Hi-Tech Conference Room'

| Devices and usages scenarios | Data rate requirements (Mbps) | % of link rate (when active) | Daily usage | Daily usage based on 8-hour day (%) | Overall activity (%) |
|---|---|---|---|---|---|
| Wireless video projection (high rate) | 100 | 40 | 2 hour/day | 25 | 10 |
| Wireless peer-to-peer file sharing (high rate) | 250 | 100 | ~ 2 Gbyte of files per day ~ 2 min/day 'on air' | 0 42 | 0.42 |
| Internet connection (high rate) | 250 | 100 | | 1 | 1 |
| **Total activity for Average user** | | | | | **11.42 %** |

Using the above usage and activity factors, and based upon an estimate of possible population densities within a building for the 'Power User', 'Average User', and hi-tech conference rooms, an overall building activity factor can be obtained, as shown in the following table.

**Table 4. Overall building activity factor**

| User | Overall user activity | Population density (% of employees) | Overall building activity |
|---|---|---|---|
| Power user | 8 38 | 15 | 1 26 |
| Average user | 2 70 | 80 | 2 16 |
| Average conference room | 11 42 | 5 | 0 57 |
| **Total average building activity (average 'on-air' %)** | | - | **3.99** |

From the above table, an overall activity factor, which identifies the average 'on-air' time, averaged over the population of the building, yields less than 5% total activity. This also compares well with longer term, high usage WLAN activity factors documented in ITU-R M.1454.

## II. Home environment

A similar market and application analysis can be done for the future home environment that will contain a number of possible UWB emitters. The following tables identify possible applications and usage models that should be appropriate for determining the activity factor for a number of possible home environments. In this case, it is anticipated to see UWB enabled devices in both a PC cluster of devices as well as a CE cluster of devices (note that the previous office environment was dominated by the PC cluster, for obvious reasons). Also, it seemed reasonable to identify three types of homes labeled here as 'Power Home 1, 2, and 3' in order to separate homes that may use very high-end and expensive components compared to homes that may have a mix of high-end and low-end components. The following tables describe example future UWB device usage and operational scenarios for the home.

**Table 5. Device and usage scenarios for Power Home 1**

| Devices and usages scenarios | Data rate requirements (Mbps) | % of link rate (when active) | Daily usage | Daily usage based on 16-hour day (%) | Overall activity (%) |
|---|---|---|---|---|---|
| **PC Cluster** | | | | | |
| Mice/ tracking balls/ pointers (low rate) | 0 016 | 0 16 | 45 min/day | 4.6875 | 0 0075 |
| Keyboards (low rate) | 0.016 | 0.16 | 45 min/day | 4.6875 | 0 0075 |
| PC speakers (low rate) | 0.448 | 4 48 | 1 hour/day | 6.25 | 0 28 |

| | | | | | |
|---|---|---|---|---|---|
| Laser printer (low-end) (medium rate) | 100 | 100 | ~ 100 Mbytes of files per day ~ 0 5 min/day 'on air' | 0.052 | 0 052 |
| MP3 players (flash based) for file downloads (medium rate) | 100 | 100 | 2x weekly @ 100 Mbyte each ~1 min total (max) | 0 015 | 0 015 |
| PDAs for file downloads (calendar/email synchronization) (medium rate) | 100 | 100 | 1x daily @ 100 Mbyte each ~ 0.5 min total (max) | 0 10 | 0 10 |
| Digital camera downloads (medium rate) | 100 | 100 | 2x weekly @ 200 Mbyte each ~ 1 min total | 0 10 | 0.10 |
| Wireless monitor (laptop to external monitor w/compression) (high rate) | 10 | 4 | 2 hours/day | 12.5 | 0 5 |
| Scanner (high-end) (high rate) | 250 | 100 | ~ 500 Mbyte of files per week ~ 0 5 min/week 'on air' | 0.0074 | 0.0074 |
| External Hard-drive for drive backups (high rate) | 250 | 100 | 2x weekly @ 2 Gbyte each ~ 2 min each (max) | 0 060 | 0 060 |
| Internet connection (high rate) | 250 | 100 | | 0 1 | 0 1 |
| **CE Cluster 1 (Home theater)** | | | | | |
| Stereo speakers (surround sound with 7 channels) (medium rate) | 16 | 16 | 2 hours/day | 12.5 | 2 |
| Wireless video projector for home theater (high rate) | 100 | 40 | 2 hours/day | 12 5 | 5 |
| PVP/PVR/Personal player movie download (high rate) | 250 | 100 | ~5 Gbytes/week ~ 3 min/week | 0.045 | 0.045 |
| Internet surfing via web tablet (medium rate) | 100 | 100 | | 0.1 | 0 1 |
| Wireless video phone (high rate) | 10 | 4 | 1 hour/day | 6 25 | 0.25 |

| | | | | | |
|---|---|---|---|---|---|
| **CE Cluster 2 (Main room)** | | | | | |
| HDTV streaming from set-top box (high rate) | 30 | 12 | 6 hours/day | 37.5 | 4.5 |
| Internet surfing via web tablet (medium rate) | 100 | 100 | | 0.1 | 0.1 |
| **Total activity for Power Home 1** | | | | | **13.23 %** |

## Table 6. Device and usage scenarios for Power Home 2

| **Devices and usages scenarios** | **Data rate requirements (Mbps)** | **% of link rate (when active)** | **Daily usage** | **Daily usage based on 16-hour day (%)** | **Overall activity (%)** |
|---|---|---|---|---|---|
| **PC Cluster** | | | | | |
| Mice/ tracking balls/ pointers (low rate) | 0 016 | 0 16 | 45 min/day | 4.69 | 0.0075 |
| Keyboards (low rate) | 0 016 | 0.16 | 45 min/day | 4 69 | 0.0075 |
| PC speakers (low rate) | 0.448 | 4.48 | 1 hour/day | 6.25 | 0.28 |
| Laser printer (low-end) (medium rate) | 100 | 100 | ~ 100 Mbytes of files per day ~ 0.5 min/day 'on air' | 0.052 | 0.052 |
| MP3 players (flash based) for file downloads (medium rate) | 100 | 100 | 2x weekly @ 100 Mbyte each ~1 min total (max) | 0 015 | 0 015 |
| PDAs for file downloads (calendar/email synchronization) (medium rate) | 100 | 100 | 1x daily @ 100 Mbyte each ~ 0 5 min total (max) | 0.10 | 0.10 |
| Digital camera downloads (medium rate) | 100 | 100 | 2x weekly @ 200 Mbyte each ~ 1 min total | 0.10 | 0.10 |
| Scanner (high-end) (high rate) | 250 | 100 | ~ 500 Mbyte of files per week ~ 0.5 min/week 'on air' | 0 0074 | 0 0074 |

| | | | | | |
|---|---|---|---|---|---|
| External Hard-drive for drive backups (high rate) | 250 | 100 | 2x weekly @ 2 Gbyte each ~ 2 min each (max) | 0.060 | 0 060 |
| Internet connection (high rate) | 250 | 100 | | 0 1 | 0.1 |
| **CE Cluster 1 (Main room)** | | | | | |
| Stereo speakers (surround sound with 7 channels) (medium rate) | 16 | 16 | 2 hours/day | 12 5 | 2 |
| HDTV streaming from set-top box (high rate) | 30 | 12 | 6 hours/day | 37 5 | 4.5 |
| PVP/PVR/Personal player movie download (high rate) | 250 | 100 | ~5 Gbytes/week ~ 3 min/week | 0.045 | 0 045 |
| Internet surfing via web tablet (medium rate) | 100 | 100 | | 0 1 | 0.1 |
| Wireless video phone (high rate) | 10 | 4 | 1 hour/day | 6 25 | 0 25 |
| **Total activity for Power Home 2** | | | | | **7.63 %** |

## Table 7. Device and usage scenarios for Power Home 3

| **Devices and usages scenarios** | **Data rate requirements (Mbps)** | **% of link rate (when active)** | **Daily usage** | **Daily usage based on 16-hour day (%)** | **Overall activity (%)** |
|---|---|---|---|---|---|
| **PC Cluster** | | | | | |
| Mice/ tracking balls/ pointers (low rate) | 0 016 | 0.16 | 45 min/day | 4 69 | 0 0075 |
| Keyboards (low rate) | 0.016 | 0 16 | 45 min/day | 4 69 | 0.0075 |
| PC speakers (low rate) | 0 448 | 4 48 | 1 hour/day | 6.25 | 0.28 |
| Laser printer (low-end) (medium rate) | 100 | 100 | ~ 100 Mbytes of files per day ~ 0 5 min/day 'on air' | 0 052 | 0 052 |
| MP3 players (flash based) for file downloads (medium rate) | 100 | 100 | 2x weekly @ 100 Mbyte each ~1 min total (max) | 0.015 | 0.015 |

| | | | | | |
|---|---|---|---|---|---|
| PDAs for file downloads (calendar/email synchronization) (medium rate) | 100 | 100 | 1x daily @ 100 Mbyte each ~ 0 5 min total (max) | 0 10 | 0 10 |
| Digital camera downloads (medium rate) | 100 | 100 | 2x weekly @ 200 Mbyte each ~ 1 min total | 0 10 | 0 10 |
| External Hard-drive for drive backups (high rate) | 250 | 100 | 2x weekly @ 2 Gbyte each ~ 2 min each (max) | 0.060 | 0.060 |
| Internet connection (high rate) | 250 | 100 | | 0 1 | 0 1 |
| **CE Cluster 1 (Main room)** | | | | | |
| PVP/PVR/Personal player movie download (high rate) | 250 | 100 | ~5 Gbytes/week ~ 3 min/week | 0.045 | 0.045 |
| Internet surfing via web tablet (medium rate) | 100 | 100 | | 0 1 | 0 1 |
| Wireless video phone (high rate) | 10 | 4 | 1 hour/day | 6.25 | 0 25 |
| **Total activity for Power Home 3** | | | | | **1.12 %** |

Finally, the above home usage models can be combined, based upon a 'best guess' regarding population densities for these types of homes, including homes that either have no UWB devices or homes with average activity factors << 1 %, to estimate a total average home activity factor to be used in the aggregate interference analysis. The results of our best estimates are shown in the following table

**Table 8. Overall home activity factor**

| **Average Home Activity** | **Overall cluster activity** | **Population density (% of homes)** | **Overall average activity** |
|---|---|---|---|
| Power Home 1 | 13.23 | 5 | 0.66 |
| Power Home 2 | 7 63 | 25 | 1.90 |
| Power Home 3 | 1 12 | 55 | 0.62 |
| Non-UWB Home (or << 1% UWB usage) | 0 | 20 | 0 |
| **Total average home activity (average 'on-air' %)** | | | **3.18 %** |

## III. Summary of results on activity factor

Tables 4 and 8 summarize the overall average activity factors that could reasonably be expected for the office and home environment, based upon reasonable 'best guess' estimates on the future usage of UWB enabled devices. In particular, Table 4 suggests that an office building, after averaging over different types of offices and conference rooms, should have no more than an overall activity factor of less than 4% Similarly, the total average home activity factor, averaged over different types of homes, is shown in Table 8 to be about 3 %. To further err on the conservative side, it is suggested that the analysis for the aggregation of uniformly distributed UWB emitters assume a 10% activity factor.